Kansas Agricultural Experiment Station Research Reports

Volume 6
Issue 5 *Kansas Field Research*

Article 8

2020

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Recommended Citation

Barnhart, I. H.; Mayor, L.; and Ciampitti, I. A. (2020) "Investigating the Use of Unmanned Aerial Vehicles and High-Resolution Multispectral Imagery to Characterize Grain Sorghum Senescence Patterns," *Kansas Agricultural Experiment Station Research Reports*: Vol. 6: Iss. 5. https://doi.org/10.4148/2378-5977.7924

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Abstract

Grain sorghum is important to producers around the world. In precipitation-limited environments, sorghum is the grain of choice because it is able to produce grain yields with limited precipitation. Plant breeders place a priority on breeding for a characterized form of post-flowering drought-tolerance, known as stay-green (SG). Assessing thousands of plots for this trait can be labor intensive and time consuming, so the goal of this study was to use unmanned aircraft vehicles (UAVs) equipped with high resolution cameras to characterize and quantify senescence patterns in grain sorghum. A field experiment with 20 hybrids was planted in Manhattan, KS. The UAV used was a Matrice 200 equipped with a MicaSense RedEdge-MX camera, and data was collected at four different sorghum growth stages. Vegetative indices (VIs) were computed from the multispectral data, including the normalized difference vegetative index (NDVI), normalized difference red edge (NDRE) index, the simple ratio (SR), green chlorophyll index (GCI), and the red edge chlorophyll index (RECI). Correlation and regression analyses were conducted to determine both the relationship of ground-measured senescence scores and the depth of senescence detection into the canopy. Results showed weak to no VI correlation with ground-truth senescence scores. Significant R2 coefficients were shown between VIs and ground-truth senescence ratings at physiological maturity with the first 7 leaves of the canopy. We therefore conclude that the Mica- Sense RedEdge-MX may not be the most effective camera to determine grain sorghum senescence patterns.

Keywords

grain sorghum, senescence, stay-green, unmanned aerial vehicles, multispectral imaging

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Summary

Grain sorghum is important to producers around the world. In precipitation-limited environments, sorghum is the grain of choice because it is able to produce grain yields with limited precipitation. Plant breeders place a priority on breeding for a characterized form of post-flowering drought-tolerance, known as stay-green (SG). Assessing thousands of plots for this trait can be labor intensive and time consuming, so the goal of this study was to use unmanned aircraft vehicles (UAVs) equipped with high-resolution cameras to characterize and quantify senescence patterns in grain sorghum. A field experiment with 20 hybrids was planted in Manhattan, KS. The UAV used was a Matrice 200 equipped with a MicaSense RedEdge-MX camera, and data was collected at four different sorghum growth stages. Vegetative indices (VIs) were computed from the multispectral data, including the normalized difference vegetative index (NDVI), normalized difference red edge (NDRE) index, the simple ratio (SR), green chlorophyll index (GCI), and the red edge chlorophyll index (RECI). Correlation and regression analyses were conducted to determine both the relationship of ground-measured senescence scores and the depth of senescence detection into the canopy. Results showed weak to no VI correlation with ground-truth senescence scores. Significant R2 coefficients were shown between VIs and ground-truth senescence ratings at physiological maturity with the first 7 leaves of the canopy. We therefore conclude that the MicaSense RedEdge-MX may not be the most effective camera to determine grain sorghum senescence patterns.

Introduction

Grain sorghum [*Sorghum bicolor* (L.) Moench] is an important crop grown worldwide (Stefoska-Needham et al., 2015). It is used as a food source for humans and animals, as well as in biofuel production systems. It is especially important to the world's dryland cropping systems, being well-adapted to precipitation-limited environments (Jordan et al., 2012). When compared to field corn, sorghum has an economic and yield advantage in dry environments (Mullet et al., 2001). Many grain sorghum genetic lines have the ability to resist post-flowering drought stress that can severely limit grain yields (Sanchez et al., 2002). This ability is in part because of the "stay-green" (SG)

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trait, which has been defined as a trait giving plants the ability to stay green under post-flowering drought conditions. This trait is considered very important by several agronomic breeders, as breeding this trait to other lines could help to increase world-wide sorghum yields (Duvick et al., 2004). In large-scale breeding trials, the SG trait has been measured primarily visually, but doing so can be very labor-intensive. With the increased use of unmanned aerial vehicles (UAVs) and high-resolution imaging in agriculture, new opportunities arise to quantify this trait with said sensors. As UAV data has been used to evaluate and quantify plant health in the past, using UAVs would potentially allow breeders to evaluate many plots with ease and efficiency. Therefore, the goal of this experiment was to assess the ability of UAVs and multispectral imagery to detect grain sorghum senescence patterns.

Procedures

This experiment was conducted in collaboration with Corteva Agriscience in Manhattan, KS. In 2019, 20 Pioneer grain sorghum hybrids released from 1963 to 2017 years were planted in a randomized complete block design, with three replications per hybrid. Experiment plots were planted in 8 rows on 30-inch row centers. Plots were arranged in dimensions of 17.5 ft × 20 ft. Planting was done on June 8, 2019, with a planting population of 70,000 seeds/a. Soil fertility was maintained based on results of soil samples, and pests were controlled as needed with chemical control products.

Flights were conducted with a DJI Matrice 200 (DJI, Shenzhen, China) equipped with a MicaSense RedEdge-MX multispectral camera (MicaSense, Seattle, Washington, USA). The camera was a 5-lens camera capable of capturing 5 simultaneous bands on the electromagnetic spectrum (blue, green, red, red edge, and near infrared). Flights were conducted based on sorghum growth stage, and took place at flowering (F), soft dough (SD), hard dough (HD), and physiological maturity (M). Flights were flown under clear, sunny conditions within 2.5 hours of solar noon. This was done to keep lighting conditions the same for all measurement periods. Flights were controlled with the DJI Pilot application and were flown with GPS waypoint mapping missions. Flight altitude was set at 100 feet (30 meters), and the UAVs were flown with a front and side overlap of 80%. The camera was set to take an image every 2 seconds to ensure sufficient numbers of images for later processing. Images captured in-flight were stored to an on-board SD card. Calibration images were taken before and after each flight to ensure image quality. In addition, 4 ground targets were placed around the experiment and real-time kinematic points were taken on these targets to aid in the accuracy of image processing.

Within 2 days of each flight, ground-truth senescence measurements were taken on each plot. Due to time constraints, 5 consecutive plants were set aside for visual scoring in the 7th row of each plot. Visual senescence ratings were taken of each plant from flag leaf to the first consecutive leaf that was completely senescent. This scale ranged from 100 (no visible senescence) to 0 (complete leaf mortality). In order to identify these plants from aerial imagery, elevated ground targets were placed between the 5th and 6th row (Figure 1A). This was done to avoid shading the plants on which measurements were taken, and the length of the target corresponded to the length of the 5 plants in row 7.

Image processing was done in Agisoft Metashape (Agisoft, St. Petersburg, Russia). Images were processed into an orthomosaic photo using a procedure of aligning photos, generating a sparse point cloud, a dense point cloud, and digital elevation model. The resulting orthomosaic photo was then exported to ArcGIS Pro (ESRI, Redlands, California, USA) for data extraction. Locations of the measured plants were found, and polygons were drawn in each plot to create a boundary where data from plants could be extracted (Figure 1B). Each orthomosaic photo was classified with a pixel-based support vector machine to remove background noise. Images were classified into four categories: sorghum leaves, shadows, soil, and grain heads. Classification accuracies for sorghum leaves were checked and were found to be between 88–94% for each measurement day. After this, vegetative indices (VIs) were computed, based on spectral information gathered from the multispectral camera. These were the normalized difference vegetation index (NDVI), normalized difference red edge index (NDRE), simple ratio (SR), green chlorophyll index (GCI), and red edge chlorophyll index (RECI). A conditional statement was then built using the "Con" tool to extract information from the sorghum leaves class, thus masking features on which measurements were not taken. The average VI value was then extracted and exported for statistical analysis in R (R Core Team, Vienna, Austria).

Statistical analysis involved comparing the average senescence scores with the average VI values from each plot. To observe changes in visual senescence, only leaves rated as 100 at flowering were used, as sorghum plants are expected to have 100% of their leaf area at this stage. Visual senescence measurements were averaged for each leaf to form a "plant" score, and these plant scores were averaged to form a "plot" score. The average plot score was correlated with the average VI using Pearson's correlation coefficients. To determine if VI data were related to certain leaves within the canopy, the first 8 leaves of each plant were averaged to form an average leaf score for each plot. Regression analysis was then performed to determine this relationship.

Results

Pearson's correlation coefficients revealed little to no correlations between VI data and the average plot measurements (Table 1). Regression analysis indicated that the majority of significant relationships were found between the NDRE and SR indices and the first 7 leaves at the physiological maturity stage (Table 2). Significant R^2 values ranged from 0.08–0.17 for the NDRE, and between 0.08–0.13 for the SR. No significance patterns were observed with SD and HD measurements.

Table 1. Correlations between average plot senescence scores and average vegetative indices values extracted

Stage	NDVI	NDRE	SR	GCI	RECI
SD	0.114[a]	0.124	-0.002	-0.139	-0.063
HD	0.028	0.11	0.004	-0.144	-0.095
M	0.118	0.308	0.205	-0.165	-0.025

[a]Pearson's correlation coefficients.
NDVI = normalized difference vegetation index. NDRE = normalized difference red edge index. SR = simple ratio. GCI = green chlorophyll index. RECI = red edge chlorophyll index.

Table 2. Regression R^2 values for determining depth of canopy senescence detection

	Soft dough					Hard dough					Maturity				
Leaf	NDVI	NDRE	SR	GCI	RECI	NDVI	NDRE	SR	GCI	RECI	NDVI	NDRE	SR	GCI	RECI
1	0.00	0.05	0.01	0.00	0.01	0.02	0.01	0.01	0.00	0.01	0.06 *	0.10 **	0.10 **	0.00	0.01
2	0.00	0.08 **	0.01	0.01	0.02	0.01	0.06 *	0.01	0.01	0.00	0.05 *	0.17 ****	0.13 ***	0.00	0.00
3	0.00	0.03	0.02	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.03	0.14 ***	0.10 **	0.01	0.00
4	0.00	0.00	0.01	0.00	0.01	0.00	0.00	0.00	0.02	0.00	0.02	0.10 **	0.08 **	0.02	0.00
5	0.00	0.01	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.03	0.08 **	0.08 **	0.01	0.00
6	0.01	0.02 *	0.02	0.00	0.00	0.01	0.02	0.01	0.00	0.00	0.04	0.16 ***	0.09 **	0.01	0.00
7	0.01	0.04	0.00	0.04	0.02	0.01	0.02	0.01	0.01	0.00	0.04	0.09 **	0.09 **	0.00	0.01
8	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.01	0.00	0.02	0.00	0.01	0.03	0.00

Significant R^2 values were seen between NDRE and SR values computed for the maturity stage when regressed against average ground-measured senescence scores for each leaf.
NDVI = normalized difference vegetation index. NDRE = normalized difference red edge index. SR = simple ratio. GCI = green chlorophyll index. RECI = red edge chlorophyll index. *, $P \leq 0.1$; **, $P \leq 0.05$; ***, $P \leq 0.01$; ****, $P \leq 0.001$.

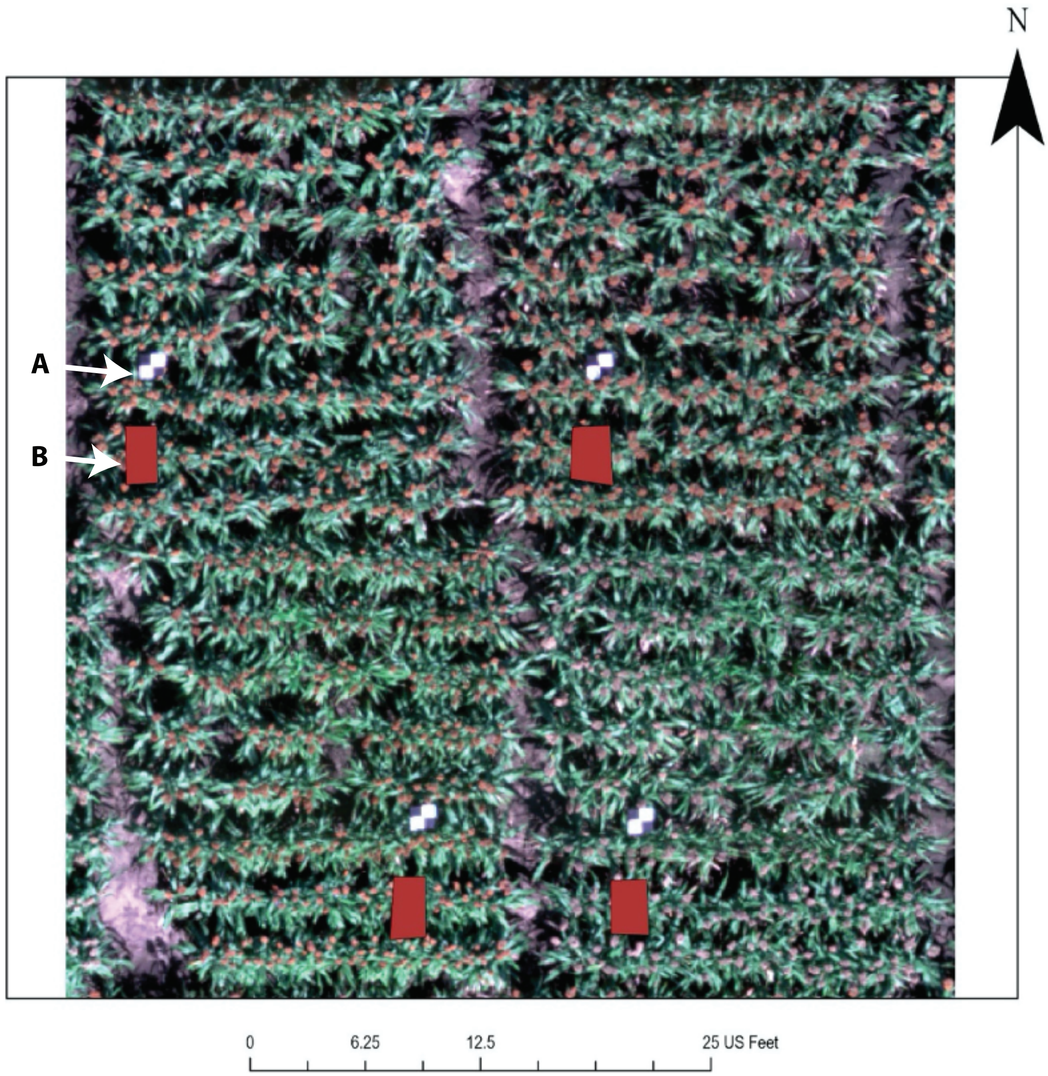

Figure 1. Ground targets (A) were set up in each plot to identify plants that were measured; shape file polygons (B) were then created around these plants for data extraction.